STANDING WAVE ON A STRING

IDEA TO REMEMBER!

Every object resonates at a natural frequency!

OBJECTIVE:

Investigating the relationship between the frequency of the vibration and tension in the string to produce a standing wave.

MATERIALS:

Tape Measure

String and scissors

PASCO String Vibrator

PASCO 550 Interface

Banana jack cables

Pulley with rod

Right-angle clamp

Slotted weights

2x Table clamps

2x Rods

Digital scale

Weight hanger

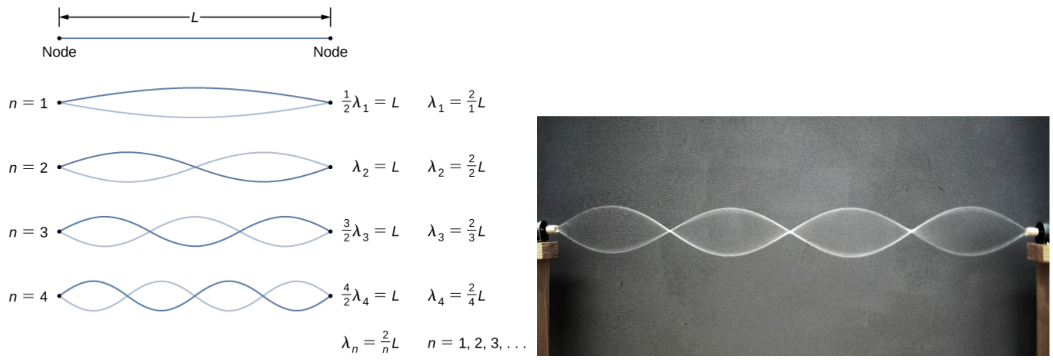
CONCEPT:

The phenomenon of string vibration has been used for thousands of years in various applications, see the *Real World Applications* for examples. But before we look at strings, let's look at the **two categories of waves!**

Think of a string where one end is held in your hand, the other end is securely fixed, and the string is stretched tightly. The string could now be flicked up or down with your hand. When this motion causes a wave, it is known as a **transverse** (meaning "across") **wave**. This is because the movement of the particles is perpendicular to (across) the propagation of the wave's movement along the string. This is in contrast to a **longitudinal wave**, where the particles move parallel to the wave. Think of water waves as opposed to sound.

CHALLENGE: Draw a longitudinal wave and a transverse wave on your worksheet for extra credit.

For this lab we will study a type of transverse wave that appears to stand still! This is called a **standing wave**, or stationary wave. This phenomenon is the result of **interference**, the combination of two waves that are traveling in opposite directions and have the same amplitude and frequency. The energy of these two waves are either added or canceled out when they are overlaid.



(a) (b)

Figure 2: Illustrations of standing wave wavelengths.

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Once combined, these two waves can produce a *natural frequency*, or **harmonic**. Harmonics occur only when there are nodes at the two ends, which are L apart. The lowest such frequency is called the *fundamental frequency* or **first harmonic**. See Figure (2), where n is the harmonic number and λ is the length of a full oscillation of the wave. Wavelength for n^{th} harmonic is shown as,

$$\lambda_n = \frac{2L}{n} \tag{1}$$

The wave velocity v is the distance λ the wave travels in a given period T,

$$v = \frac{\lambda}{T} = \lambda f \tag{2}$$

Now, we use the linear wave equation (one of the most important equations in physics and engineering) and a little calculus to extrapolate along the curve of the wave, the wave speed v is shown to be:

$$v = \lambda f = \sqrt{\frac{F_T}{\mu}} \tag{3}$$

This relates a certain frequency f, string tension F_T, and the mass per unit length of the string μ together (this length is different than the L for the wavelength between the nodes).

Real World Applications

- People have understood this standing wave/harmonic phenomenon for thousands of years, building instruments—like guitars—with strings of different densities, tensions, and lengths to create unique sounds and music!... The real question is: who is the best guitar *player*?...
- The most important example of a transverse wave are electromagnetic waves, or light! Similarly, the true power of electricity traveling through a wire is contained in the transverse and perpendicular electric and magnetic waves!

1) Using standing waves to *levitate objects!*
2) How electricity actually flows—transverse electromagnetic waves!

PRECAUTIONS:

Be cautious while you hang the masses!

PROCEDURE:

1. ☐ Fill out the top information **and** complete the memory exercise—Question M1 and M2—on the worksheet.

2. ☐ REQUIRED: Read the *Concept* section.

3. ☐ Record the string's mass per unit length μ in kilograms per meter for Question 1 on the worksheet.

4. ☐ Assemble the setup as it is shown in Figure (3).
   - 4.1. With two rods clamps to opposing sides of the table, clamp the PASCO String Vibrator to a rod and tie a string through the hole in the metal tab.
   - 4.2. Attach the pulley to the table rod with a right-angle clamp so that the pulley rod is horizontal and the pulley wheel is vertical.
   - 4.3. Hang the other end your the string over the pulley and ensure that the string is level. If not, adjust the height of the PASCO String Vibrator or pulley.
   - 4.4. Tie a weight hanger to the end of the string under the pulley.
   - 4.5. Connect the PASCO String Vibrator with two banana wires through the 8V@400mA output channels of the PASCO 550 Interface.

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CONCEPT & PROCEDURE VIDEOS:

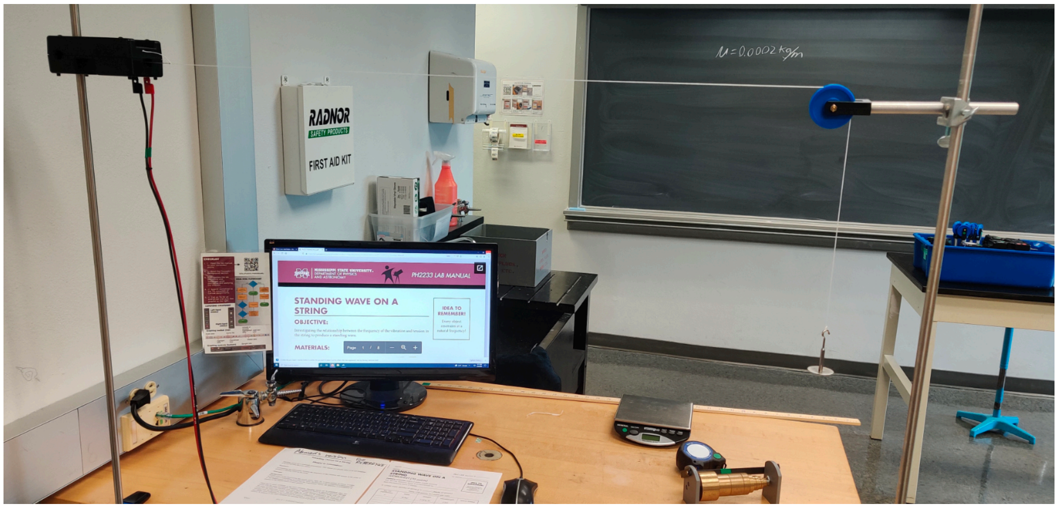

Figure 3: Setup of the experiment.

5. ☐ Measure the length L between the end points (from vibrator to pulley) and record for Question 2 on the worksheet.

6. ☐ Open the PASCO Capstone application, select *Hardware setup*, then click on the output channel to pick *output frequency sensor* (the yellow circle on the right).

7. ☐ Click *Signal Generator* and select a frequency (around 120Hz), and click "ON." (You can increase amplitude to 2–3 volts if amplitude is low.)

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8. ☐ Introduce some masses onto the weight hanger to adjust the tension until the fundamental frequency of the string matches with the Vibrator's fixed frequency.

9. ☐ Measure the weight *F* of the hanging mass.

10. ☐ Calculate wavelength λ and wave speed v (refer to the *Concept* section above).

11. ☐ Repeat steps 5–7 and fill Table 1 in your worksheet.

12. ☐ Answer Questions 3–9 on the worksheet and follow the **Let's THINK!** instructions below.

Let's THINK!

- **Ask questions**: What are you learning here?... Why is this Physics concept important and how can it be used?... What do you not understand?... (For more information on this Physics topic, scan the QR codes in the *Real World Applications* and at the start of the *Procedure* section.)
- **Discuss** the concept and demonstration with your partner to help each other understand better. Discussion makes learning active instead of passive!
- For **FULL PARTICIPATION [15 points]** you must call on the TA when you have finished your group discussion to answer some comprehensive questions. If you do not fully understand and the TA asks you to discuss more, you must call on them one more time to be dismissed with full marks.
- **CONCLUSION [10 points]**: In the Conclusion section at the end of the worksheet, write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those as well.

Updated Date	Personnel	Notes
2022.08	Chase Boone, Udeshika Perera, Ahmad Sohani, Brooks Olree	2022 Summer Improvement: Created new format.
2022.09, 2023.01	Chase Boone, Bryan Semon, Rongjing Yan	Improvements and clarifications.

Name: ______________________________ *PH1123* Section #:__________

Name: ______________________________ TA Name:____________________

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WORKSHEET [70 points]

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Memory exercise [each 2 extra credit points]:

M1) Spring reaction force is proportional to ________________

M2) All oscillations have 3 things: ________________________

1) Linear mass density of string μ = ________Kg/m [1 points]

2) Length L between the end points __________m [2 points]

3) Mass of hanger ______kg [1 points]

Table 1 [15 points, 0.5 point per cell]

No. Of Harmonics n	Mass M (kg)	Weight $F = M{*}g$ (N)	Wavelength λ (m)	Wave speed v (m/s)

4) Plot the wave speed v vs the wavelength λ using Excel or graph paper. (Ask your TA to sign below to indicate that they saw your plot and approved.) [10 points]

TA Signature/Initials: ____________________

5) Find the slope of the plot from Question 3. What is the physical meaning of the slope? What are the units? [8 points]

6) What physics term is shown by the slope? __________ [3 point]

7) What is the unit of the slope? ______________________ [5 point]

8) What is the frequency *f* of the oscillator? __________ [5 point]

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9) Explain why the wavelength expression $\lambda_n = \frac{2L}{n}$ does not make sense for a non-integer *n*? (You can show it in mathematical expressions or pictures.) [10 points]

10) Answer the "***CHALLENGE***" from the *Concept* section. [3 extra credit points]

Conclusion

Write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those here as well. [10 points]

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